

Dear Tom and Barbara,

I wish to provide you with the input that you have requested, regarding the long-range plans of STAR for the relativistic heavy ion physics white paper. First I enclose the STAR Long Range Plan document, which is the report of the STAR Long Range Plan Committee and which represents STAR's view of its future plans. In addition to this document, I will attach a "white paper" for STAR from me, which should serve to fulfill your request for input for the relativistic heavy ion physics white paper. I wish to point out that this "white paper" for STAR is my view as spokesperson and not an official STAR response, as there has been insufficient time to go through a process of discussion and acceptance of these ideas in STAR. However, this paper will now go to STAR for review and modification in time for final changes before the Long Range Plan Town Meeting. As you will see, my view is the STAR view, with the exception of my more conservative time-line, which I feel is more realistic given what already appears to be a diminished amount of operating time for experiments over the first few years at RHIC. I expect that the general timeline in the Long Range Plan for RHIC should become an important point of discussion in the next workshop and will need consensus prior to submission of a white paper for this field.

If you wish additional input, or clarification please do not hesitate to contact me.

Regards,

John

## **Draft “White Paper” for STAR for the Period 2001 – 2010<sup>1</sup>**

(response to a request from B. Jacak and T. Ludlam for input to the  
Relativistic Heavy Ion White Paper)

John Harris

### **SUMMARY STATEMENTS**

- 1) The highest priority for STAR is to be able to carry out the initial phase of its scientific program at RHIC. This requires that the STAR detector systems be completed as initially proposed with sufficient funding for completion of the baseline plus additional experimental equipment (AEE) detector systems.

This requires timely completion of the Barrel and End Cap Electromagnetic Calorimeter systems.

Next, it is imperative that sufficient data be accumulated to be able to answer the important questions, which were the foundation of the entire RHIC concept and the reason for its construction and operation. The general questions to be answered are 1) what are the properties of matter at the high energy densities expected at RHIC and 2) are new states of matter created? The goal of the RHIC program over its first five years (2000 – 2005) is to answer these questions.<sup>2</sup>

To be able to discover the answers to these questions RHIC must operate for experiments for periods of approximately 32 weeks per year, as originally planned.

It is expected that once the STAR and PHENIX (baseline + AEE) detector systems are completed (circa 2003), an intensive and more detailed discovery phase will begin and evolve into a characterization phase including correlations of observables and exotic probes.

Several detector additions to STAR (near the end of the first phase, 2003 - 2005) will be requested, in order to introduce capabilities to uncover new physics and increase its phase space coverage. This will allow STAR to measure exotic processes, and correlate them with other measurements made over a larger acceptance in the same events, in order to determine the properties of matter at high energy density and whether novel states are formed.

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<sup>1</sup> This paper is derived from the STAR Long Range Plan document, representing STAR’s view of its future plans. The STAR Long Range Plan document is on the web at <http://www.star.bnl.gov/STARAFS/smd/lrp/lrp-2001.ps>

<sup>2</sup> This timescale (2000 – 2005) differs somewhat from that presented in the STAR Long Range Plan (2000 – 2003), but is perceived to be more realistic at this time.

In order for STAR to reach its full capabilities for tracking and particle identification over a large acceptance, as originally conceived, a Barrel Time-of-Flight system will be requested for construction and installation in 2003 – 2004.<sup>3</sup> In addition, STAR will upgrade its DAQ and trigger rate capabilities during this period, in order to utilize effectively the RHIC luminosity. It is expected that the correspondingly higher data rates will be mirrored by commensurate upgrades of the bandwidth, reconstruction, and analysis capabilities at the RHIC Computing Facility. The highest priority for new detectors near the end of this phase (2004 – 2005) will be the construction and installation of a micro-vertex detector system for measuring open charm. In addition, tracking and particle identification will be extended forward, and adjacent to the present TPC tracking and particle identification acceptance.

2) If new states of matter are discovered (i.e. the answer to the second question above is positive), then the properties of the new state(s) of matter must be established followed by an understanding of the resultant new physics. This is the goal of the second five years (2006 – 2010) of RHIC experiments. This will require a characterization of the properties of the new state(s) of matter. This characterization will require more detailed correlations between various observables and will evolve to include the use of rare probes.

In order to fully characterize the properties of the new state(s) of matter at RHIC and understand theoretically any new physics derived from these measurements, it is imperative to be able to study processes which have low cross sections, such as those at high mass or extremely high  $p_t$ . This will require a luminosity upgrade for RHIC and a major upgrade to STAR (near the beginning of the second phase in 2006 - 2007). It requires establishment of an R&D program during the early phase of RHIC to be able to design, test and prototype new detectors for the upgrade and the future. It also requires upgrading of the RHIC Computing Facility to be able to keep up with the data bandwidths, reconstruction, and analysis of data.

The major upgrade to STAR will require replacement of the time projection chamber (TPC) with a fast tracking detector with particle identification. Detailed study is still needed for the design of this new system. Extended coverage in the forward direction is also anticipated. However, significant R&D is still needed to decide upon a design of the upgrade system. The cost of the STAR R&D program, which is necessary to develop new STAR detectors for the first ten years of RHIC and to maintain an ongoing physics program, is estimated in the Appendix. The cost of this program has been developed since and as a result of the STAR Long Range Plan document.

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<sup>3</sup> A significant contribution to this construction is expected to come from foreign resources.

## **SUPPORTING DISCUSSION**

The goal of the first phase of RHIC (2000 – 2005) is to determine the properties of matter at high energy densities and to ascertain whether novel states of matter are formed in this regime. Specifically, this involves determining the behavior of the strongly interacting matter excited in RHIC collisions, and determining whether it undergoes a phase transition

- from a state of deconfined quarks and gluons at high energy density to the cold hadrons that are observed in the final state at RHIC
- from a state where chirality is a fundamental symmetry to one where it is broken, as in our everyday world.

These questions can be answered in STAR by studying properties of the deconfinement and chiral phase transitions. *To establish the existence of a deconfined state (and corresponding phase transition)* various thermodynamic properties will need to be measured and their relative behavior established as conditions are changed in a controllable manner. These properties include most importantly the temperature, specific heat, energy density, and entropy density (including the flavor content). Most of these are only accessible to experiment after comprehensive measurements of many observables in similar event classes, or preferably in individual events. Specifying strict conditions for single events or event classes serves to control the experimental conditions. *To establish the existence of a chirally symmetric state* in these collisions, the behavior of various particles/resonances (with a variety of lifetimes on the order of the lifetime of the chirally restored phase) and the effect of the medium on their masses and widths must be studied as a function of energy density or temperature. These studies will include the measurement of both the hadronic and leptonic decay modes of the resonances. All of these investigations require the flexibility of RHIC to collide a variety of beams over its energy range.

STAR provides a large acceptance for the measurement of many physical observables, some of which can be determined for each individual event. It allows a measurement of the momentum space density ( $d^3\sigma/dp^3$ ) of identified particles, precision measurements of the correlations of various particles (and in the future - jets, photons, and particles), high  $p_t$  phenomena, flavor (strange and in the future - charm) production, possible collective or coherent phenomena (particle flow, coherent Bose-Einstein behavior at high densities, disoriented chiral-condensates), and fluctuations which are expected to occur during the phase transition. Fluctuations may arise in the quark/gluon to hadron phase transition and in the chiral phase transition from domains of chiral-condensate to individual hadrons.

1) During the first 2 or 3 years, a large part of the STAR physics program at RHIC will involve the measurement and study of the soft hadronic physics ( $p_t < 2$  GeV/c) observables, which involve primarily single particle spectra, multi-particle correlations and event-by-event studies. These provide information on the degree of chemical and thermal equilibrium, flavor equilibrium (strangeness content),

entropy production, baryo-chemical potential, energy and particle densities of the system, the degree of transformation of the relative motion into internal degrees of freedom, the space-time evolution of the system, possible collective phenomena (such as collective nuclear flow, disoriented chiral condensates), the system temperature, and possible in-medium effects. These studies will require a comparison of the behavior of various nuclear systems at different collision energies in order to obtain an understanding of the systematic behavior of the above quantities as a function of the energy density and the system mass.

STAR will complete its baseline and AEE detector systems with the addition of the silicon vertex tracker (2001), forward time projection chambers (2001), barrel electromagnetic calorimeter (2001 – 3), and higher level triggering capabilities (2001 – 3). Also funded for installation during this initial phase at RHIC are an endcap electromagnetic calorimeter (U.S. National Science Foundation, 2002 – 3), time-of-flight patch (STAR and DOE, 2001), silicon strip detector (French groups in STAR, 2002), and a photon multiplicity detector (Indian groups joining STAR, 2002). Funds will be sought for a data-acquisition rate increase (STAR and DOE, 2001 – 3), and a barrel time-of-flight (DOE and Chinese NSF, 2003 – 4)<sup>4</sup> to complete the mid-rapidity coverage with particle identification capabilities.

Upon completion of the barrel electromagnetic calorimeter, STAR will embark upon more detailed studies of high  $p_t$  physics with the added capability to measure the electromagnetic energy and to identify electrons. This will allow triggering on and measuring high  $p_t$  phenomena in the form of jets, direct photons, and high  $p_t$  particles. It will also enable STAR to measure and trigger on electron-pairs. The result will be studies of  $J/\psi \rightarrow e+e-$  and  $\phi \rightarrow e+e-$  decays. This will allow STAR to study charmonium suppression and possible effects of medium modification of vector mesons by comparing the lepton and hadron decays channels. With the addition of a micro-vertex detector system late in this initial phase, STAR will be able to measure open charm production, which is crucial to understanding the production of charm and the suppression of charmonium states.

Another aspect of the physics program is to study high transverse momentum phenomena, where perturbative QCD can be used to predict the behavior and experimental observations. This high  $p_t$  physics program ( $p_t > 2$  GeV/c) will determine the initial conditions in the collisions (nuclear structure functions and the degree of nuclear shadowing) and parton propagation and jet quenching in dense matter. Comparisons between heavy systems and lighter systems, including  $p + p$  and  $p + A$ , will be necessary for a complete understanding of the parton distributions in nuclei and the behavior of QCD at high energy densities. The  $p + A$  program will commence circa 2003, once the EMC coverage is sufficient for detailed measurements of jets, photons, and photon-jet coincidences.

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<sup>4</sup> See the STAR Long Range Plan document for more details.

During the second part of this phase STAR will implement new detectors which will allow it to study rare probes with high statistics. These include higher statistics for  $J/\psi$  studies, open charm, and B-decays as a function of energy density and system mass. These also allow the study of jets to significantly higher transverse energy and flavor tagging of forward jets. Additional forward tracking and particle identification detectors will be requested to allow measurements just beyond the TPC range near mid-rapidity and at very forward rapidities for more complete event characterization and understanding. Fast, high resolution tracking detectors and RICH detectors would enhance STAR's capabilities in the  $1 < \eta < 2$  range. High resolution forward silicon tracking devices at very forward rapidities (in 2004, covering  $2 < \eta < 4$  to 5) would expand the high resolution tracking coverage for event characterization and forward particle distributions. TPC read-out, DAQ, and trigger upgrades are anticipated to improve STAR's data rate capabilities and efficiencies.

Another aspect of the STAR physics program is photon/pomeron physics (resulting from the large electromagnetic fields created in ultra-peripheral collisions of heavy ions). A survey will be undertaken of the states with mass  $< 2$  GeV created in two-photon and photon-pomeron interactions in these ultra-peripheral collisions. This survey will be undertaken during the first two to three years at RHIC. In the latter years once the EMC is available, higher mass states including electron decays of higher charm states, final states containing photons, and higher mass decays of strange states can be studied. The addition of Roman pots in the extreme forward direction would allow studies of pomeron-pomeron interactions.

2) The second phase (2006 – 2010) at RHIC will involve establishing experimentally the properties of the new state(s) of matter and understanding theoretically new physics that can be derived from these measurements. This characterization of the properties of the new state(s) of matter will involve initially correlations between many observables in the soft physics realm, and an increasing dependence on hard scattering and measurements of high  $p_T$  particles, jets, direct photons, di-jets, photon-jet correlations, particle-jet correlations, and particle-photon correlations. These measurements and correlations between them will extend our understanding well into the perturbative QCD regime and allow a comprehensive understanding of parton energy loss in the medium and will provide scaling comparisons in various systems. This phase will also involve an understanding of the initial conditions of the collisions in greater detail, at higher  $Q^2$  and lower  $x$ , by measurement of the nuclear structure functions and nuclear shadowing for different initial nuclear systems. More detailed studies of  $J/\psi \rightarrow e+e^-$  and  $\phi \rightarrow e+e^-$  decays will allow STAR to study charmonium suppression and possible effects of medium modification of resonances as a function of the energy density and system size.

The need to study processes which have low cross sections, such as decays of high mass particles, processes with large  $Q^2$ , and at extremely high  $p_T$  requires a

luminosity upgrade for RHIC. It will also require a major upgrade of STAR. Furthermore, in order for the low cross section, correlation measurements discussed above (di-jets, photon-jet correlations, particle-jet correlations, and particle-photon correlations) to be undertaken at RHIC, it is imperative that the STAR acceptance and rate capabilities be upgraded along with the luminosity of the RHIC machine. This also requires a corresponding upgrade to the RHIC Computing Facility to be able to keep up with the data and analysis rates. The STAR upgrade is planned for the early part of this second phase of RHIC, and will involve replacement of the time projection chamber (TPC) with a fast tracking detector with particle identification. Various concepts are being considered, but one concept is to replace the TPC with several new layers of silicon tracking or to replace it with a new, smaller, and faster TPC. Either of these inner tracking devices could be surrounded by RICH detectors (possibly integrated with the TPC) and transition radiation tracking detectors for high momentum particle identification. However, the detectors to be used for this upgrade are yet undetermined and must emerge from R&D over the next several years. In addition, extended coverage in the forward direction is planned. A STAR R&D program, which continues over the two phases at RHIC, is necessary in order to continue to update STAR's capabilities in anticipation of progress in the physics program.

## **Appendix – STAR R&D Program**

[This is a first estimate for the cost of R&D for development, testing, and prototyping new detectors in support of the future STAR physics program.]

<b><u>Detector System</u></b>	<b><u>Cost/yr (k\$/yr)</u></b>	<b><u>Start Year</u></b>	<b><u>Duration (yr)</u></b>
<b>Micro-Vertex Tracker &amp; Forward Tracker</b>		2001	3
Mechanical Eng. + Tech	100		
Electrical Eng.	100		
Chip submissions	30		
Support Equipment	15		
<b>DAQ upgrade R&amp;D</b>		2002	2
Electrical Eng.	100		
Electronic Tech.	100		
Equip.	20		
<b>TPC upgrade + Midrapidity RICH cylinder</b>		2001	6
Detector physicist	150		
Mech Eng. + Tech	50		
Electrical Eng.	50		
Equip.	15		
<b>Resistive Plate Chamber</b>		2001	2
Elect. Eng. TDC system	100		
Mech. Eng. - system design	100		
<b>Forward RICH Dev.</b>		2001	2
Mech. Eng.	100		
Equip.	50		
<b>Scaler Development</b>		2001	2
Elec. Eng. / Coding	50		
Equip.	10		
<b>Trigger Develop.</b>		2001	2
Elec. Eng. / Coding	50		
Equip.	10		
<b>Additional Detector Develop.</b>		2003	3
Detector physicist	150		
Mech Eng. + Tech	50		
Electrical Eng.	50		
Equip.	30		